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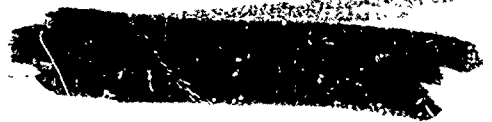
**FLUID DYNAMICS TEST PRETEST REPORT
MOL PROTUBERANCE HEATING
WIND TUNNEL MODEL
SEQUENCE NUMBER B334**



Prepared under Contract Number F04695-67-C-0029 ✓
for MOL System Program Office,
Headquarters Space and Missile Systems Organization
Air Force Systems Command
United States Air Force

IN COMPLIANCE WITH THE REQUIREMENTS OF
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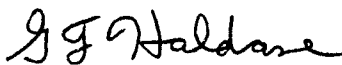
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Douglas Aircraft Company
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APPROVAL SHEET
FOR
PRETEST REPORT FOR MOL PROTUBERANCE HEATING
WIND TUNNEL MODEL

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ABSTRACT

This report outlines objectives and test requirements for wind tunnel testing of several protuberances unique to the MOL vehicle. An important feature of the testing program is the investigation of heating rates on protuberances wholly or partially submerged in a boundary layer. In order to achieve a thick boundary layer, the models are mounted on the floor of the tunnel. A thin, instrumented plate replaces the ordinary tunnel floor plates, in order to investigate the disturbances caused by the protuberances on the surrounding flow fields. A wake heating region of at least 35 inches will be available.

The protuberance models and the metric floor plate are constructed of thin nickel shells 1/16 inch thick. Heat transfer data will be collected by applying thin skin temperature response techniques. Half scale models of the VVSA, thruster, ESE fairing, and VVSA-thruster combination will be tested.

The models will be tested at Mach numbers of 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 and unit Reynolds number will be varied to the limits of the tunnel and structural limits of the models. The Mach number range corresponds to the period during the flight trajectory of most severe heating (60 to 160 seconds after liftoff). The Reynolds number range will be higher than flight Reynolds number because of tunnel limitations. With the exception of the asymmetric fairing, the models will be yawed up to 24° ; flight pitch programs cannot be simulated except by varying Mach number and other tunnel parameters.

Data will be presented primarily in the form of ratios of heat transfer, h/h_o , and pressure, P/P_o , where subscript o refers to flat plate data.

Plots will be made of boundary layer stream velocities, pressures, and Mach numbers. Temperature-time responses of the nickel shells and variations of h/h_o along the tunnel centerline will be plotted. In addition, values of h/h_o and P/P_o for the floor instrumentation will be printed on plan schematics. Shadowgraphs will be taken of the protuberances and surrounding flow fields.

DESCRIPTORS

Heat Transfer

Protuberance

NOL

Test

Wake

Wind Tunnel

PREFACE

The MOL Protuberance Heating Test will be conducted in March 1968 for the Air Force Space Systems Division under Contract Number FO4695-67-C-0029. An outline of the protuberance heating test was provided in Section 5 of SAFSL Exhibit 21010. A pretest report is required in the contract data requirements under line item 1ALL, data item No. UT-135.

The test will consist of three phases. Phase I will be a boundary layer survey of the tunnel floor, which is necessary to establish boundary layer thickness because the tunnel geometry for this test is unusual. Phase II will establish heating characteristics and pressure distributions on the floor with no protuberances. Phase III will consist of data collection on the protuberances, and the effect of the protuberances on the floor flow fields and heating rates.

Part of the test plan was previously presented in reference 1.

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1.0 INTRODUCTION

1.1 MOL Protuberance Heating Test

The protuberance heating test will be conducted at the Douglas Aerophysics Laboratory, El Segundo, California in the Four-Foot Transonic Wind Tunnel at supersonic Mach numbers with the transonic cart installed in the tunnel circuit. Wind tunnel models will be tested at Reynolds numbers as close to flight Reynolds numbers as can be attained.

1.2 Test Objectives

The primary objective of the test is to determine the aerodynamic heating rates and their distributions on the MOL protuberances, and on the skin and structures surrounding the protuberances. Other important objectives are to evaluate the effects of the protuberances on the surrounding viscous and inviscid flow fields, and compare to flat plate heating distributions and flow fields. There will be an opportunity to study wake heating effects for at least 35 inches behind the models. It is anticipated that a systematic approach to predicting inflight temperature histories on protuberances will develop from this test.

1.3 Implementation

Even though the MOL vehicle will attain Mach numbers as high as 11, the local Mach numbers around the protuberances will not exceed 5 during the time of peak heating, so a complete test program can be conducted at supersonic Mach numbers. The expected peak heating region is illustrated in figure 1.

The Douglas Aerophysics Laboratory Four-Foot Wind Tunnel is of the intermittent blowdown type. The operating envelope available for this test is shown on figure 2. This envelope is based on preliminary tests run to verify the feasibility of testing the large models with the unusual tunnel geometry necessary for this test (as explained subsequently).

The envelope is limited from running below Mach 2.5 because at that point the flow is blocked by the cooling shoe used to protect the model during start. The maximum total pressure and dynamic pressure are determined by the structural limitations of the model and usable, available run times. Resulting test conditions are included in table 1. Comparisons of test and flight Reynolds number and boundary layer thicknesses are also presented in figure 2.

1.4 Facility Scheduling

Tunnel modification was begun in January 1968. Because of heavy scheduling commitments, it will be necessary to conduct the boundary layer survey as a separate test using solid plates in the floor instead of the metric floor plate. An intervening test will be included between the boundary layer survey and primary test (Phase II).

Installation of the primary test will begin in early February, and will take several weeks. Testing is expected to begin on or near March 25.

2.0 MODEL DESCRIPTION

2.1 General Design Criteria

Heat transfer models built for applying skin temperature response techniques for gathering data are designed to meet several criteria, but of these probably the most important are the skin material and thickness. The material and thickness were selected to meet the following criteria:

$$B_1 = \frac{hd}{K} \leq .0.1$$

If the Biot Modulus is small, the errors due to temperature gradients through the skin will be diminished.

$$F_o = \frac{\alpha t}{d^2} \geq 10$$

The Fourier Modulus is a measure of the degree heating effects have penetrated the skin, so in order for there to be good thermocouple response, it must be large.

The overall result from designing to the above criteria is to minimize errors due to temperature gradients through the skin and errors caused by surface conduction from one part of the model to another. A material thickness meeting the above criteria was too thin for some model parts, so the thermal design had to be compromised in order to meet the strength requirements. All model and floor plate skin thicknesses were set at 1/16 inch nominal, and the material chosen for all parts was nickel.

References 2, 3 and 4 expand on the subject of heat transfer model design.

2.2 Metric Floor Plate

2.2.1 General Configuration

The metric floor plate assembly is made up of three basic members. The center section consists of a 41 1/4 inch diameter turntable, which is necessary to yaw the smaller models.

Forward and aft skin sections extend the metric plate to 48 inches wide by 117 inches long. All members mount on insulative supports, which in turn mount to the tunnel stringers, the floor support structure.

2.2.2 Turntable

The turntable basically consists of four sections. The metric skin is heavily instrumented with pressure taps and thermocouples. Cutouts in the surface provide access to model mounting structures underneath. An insulative support mounts the skin to a base plate. The base plate provides support for the overall assembly, and provides attachments to tunnel support structure. The joint between the turntable and other skin members will be filled before each run to diminish the possibility of the joint causing a weak shock. The turntable will yaw through $\pm 24^\circ$. The clearance gap around the skin is sealed from the transonic cart plenum with an "O" ring. Thermocouple and pressure tap patterns are provided in figure 4 and table 3.

2.2.3 Forward and Aft Skin Sections

The forward and aft metric floor plate section mount to tunnel support structure through insulative supports. Floor insulative supports and the one for the turntable are cut away wherever they are not bearing or wherever strength is not needed in order to contact the skin as little as possible (according to reference 4, the best insulator on the underside of a thin skin model is dead air). The instrumentation layouts and general dimensions are shown on figures 5 and 6 and tables 4 and 5.

2.2.4 Convection Shield

A convection shield mounts between each stringer under the metric floor plate assembly. This eliminates convection under the plate and provides support for a network of tubes that will supply the liquid nitrogen for precooling. The shields are constructed of sheet aluminum.

2.3 Thruster Assembly

The thruster assembly to be tested is shown on figures 7 and 8. The model will mount on the turntable at tunnel station 155 as shown on the installation drawing, figure 3. The pressure taps are located on one side of the model, and thermocouples on the other. By taking advantage of the symmetry of the model, a complete analysis can be made of both windward or leeward sides by yawing in both plus and minus directions. The thruster assembly will be yawed to 0° , $\pm 12^\circ$; and $\pm 24^\circ$.

The shell is reinforced by insulative bulkheads, one longitudinally positioned on the ξ , and others transversely so that unsupported sections of the skin do not exceed a square of 3 inches on a side, in an attempt to hold deflection of the surface to 0.005 inch. The back mounts separately as do both contiguous and outboard nozzles. The module mounts on a base plate which mounts to the substructure under the turntable skin.

The thruster and other models have a system of copper tubing routed to various parts of the interior. A standard pipe fitting is provided on the bottom of the base plate to accept the liquid nitrogen supply for precooling the model.

An instrumented wake length of 37 inches will be available for investigation.

2.4 VVSA - Thrustor Combination

The VVSA to be tested is shown on figures 9 and 10. The model will mount on the turntable at tunnel station 148 as shown on figure 3, and will be run only concurrently with the thrustor. As was the case with the thrustor, the VVSA is internally strengthened with insulative bulkheads, has thermocouples on one side, pressure taps on the other, and has a system of tubes for accepting liquid nitrogen. The model is mounted on a base plate. The VVSA - thrustor combination will be yawed to 0° , $\pm 12^\circ$, and $\pm 24^\circ$. A wake length of 37 inches will be available as with the thrustor alone.

2.5 Asymmetric Model

The asymmetric model is shown on figures 11 and 12. As was the case with the other two models, the interior is reinforced with bulkheads, the model mounts on a base plate, and is internally cooled. Flight trajectories for the MOL vehicle indicate it is not necessary to yaw this model. The tunnel on the side makes the model unsymmetrical, so pressure taps and thermocouples are equally distributed. The instrumentation is concentrated near the tunnel because the other surfaces are similar to model geometries of several previous wind tunnel tests.

The model leading edge will mount at tunnel station 125, and a wake heating length of 35 inches will be available.

3.0 FACILITY INSTALLATION

3.1 The Douglas Aerophysics Laboratory Four-Foot Trisonic Wind Tunnel

The Douglas Aerophysics Laboratory Four-Foot Trisonic Wind Tunnel is well suited for the MOL protuberance test for two reasons. First, it is an intermittent blowdown tunnel. The tunnel can be started and brought up to steady-state conditions abruptly, and the shoe will protect the model during this brief period of unstable flow. Thus the temperature shock is essentially a step input, and can be treated that way in data reduction without appreciable error. By contrast, if this model were floor mounted in a continuous tunnel, the temperature step input would be accomplished by increasing the tunnel freestream total temperature. Ordinarily, this means the variation of total temperature must be considered in data reduction to avoid significant errors.

The second consideration that makes the Four-Foot Tunnel attractive for this test is the flexibility in model design and the thick boundary layer made possible by the transonic cart.

3.2 The Four-Foot Wind Tunnel Transonic Cart

The transonic cart is a removable section of the tunnel that ordinarily performs several functions:

- a. The test section is extended from 5 to 12 feet long.
- b. Walls are covered with perforated steel plates to help diminish the wall boundary layer thickness and weaken shocks impinging upon them.
- c. A plenum surrounding the test section is connected upstream and downstream to the main air flow through large, remotely controlled butterfly valves. These valves control the amount of air bypassing the test section, and are thus used to vary the Mach number during transonic operation. There are approximately 14 inches between the perforated plates and the plenum outerwall.

For this project, the transonic cart will be retained in the tunnel circuit during a supersonic test for several reasons:

1. The extra length of test section is needed to thicken the boundary layer.
2. The perforated plates may be replaced with an unperforated plate, the metric floor plate, facilitating mounting the models. (It is not possible to mount models this way in the supersonic section without damaging either the sidewalls or the flexible nozzle). The support structure for the perforated plates, the tunnel stringers, are also used for mounting the model.
3. The plenum provides a means of access underneath the floor plate and models. The plenum can also be used to mount auxiliary equipment, such as the shadowgraph system and the LN2 supply, and it provides a space for routing model instrumentation leads.

3.3 Modifications to the Transonic Cart

A convection shield (already mentioned) consisting of sections of sheet aluminum will be mounted between the stringers, and a few inches below the metric floor plate.

The tunnel stringers will have to be shortened near tunnel station 160 in order to provide clearance for the turntable.

The perforated plates will be replaced with solid aluminum plates to stop air from entering the plenum and recirculating, to improve the flow, and to stop air circulation in the plenum from affecting thermocouple response by introducing convection losses.

3.4 Hydraulic Shoe

In order to protect the model during start, a hydraulically actuated shoe had to be designed. This shoe differs from standard tunnel equipment in that a piston with a 48 inch stroke was necessary (floor to ceiling).

Ordinary shoes only extend to tunnel centerline. The large size dictated a stronger shaft than is ordinarily necessary. In order to be most effective, the shoe was moved six inches forward of its usual position.

3.5 Liquid Nitrogen System

In order to achieve a good temperature rise during a blow, it will be necessary to chill the models and floor plate with liquid nitrogen, since for most Mach numbers the stagnation temperature is close to ambient. It is anticipated that the LN2 will bring the initial temperatures down to -75°F .

4.0 INSTRUMENTATION

4.1 Pressure Taps

Pressure taps are 1/16 x 0.010 inch wall stainless tubing. The distribution of pressure taps is as follows (also refer to figures 5-13):

Forward Floor Skin	6
Turntable	77
Aft Floor Skin	13
Asymmetric Fairing	24
Thrustor Assembly	31
VVSA	37

The pressures will probably be connected to two banks of scanni-valves (model D), each having five modules, with one port of each module reading a reference pressure. However, it is possible that tunnel personnel will select another type of pressure scanner. The longest lag time (for a tube 102 inches long) will be about 2 1/2 seconds. Pressures on the metric floor plate will be close to free-stream static. Maximum model pressures will approach 20 psia (ramp on the thrustor, leading edge of the VVSA, tunnel on asymmetric model).

4.2 Thermocouples

Copper-constantan thermocouples (0.012 inch diameter) are welded to the inside of the skin at the locations indicated in the figures. The small gage wire is necessary to minimize errors resulting from heat conduction along the wire.

All of the wire used in the model has been certified by Revere Corporation to have the following outputs:

<u>Temperature</u>	<u>Emf</u>
-100°F	-2.575 mv
-300°F	6.637 mv

Certificates are on file in company receiving records. Each wire and pair are insulated with nylon. Thermocouple distribution among the model parts is as follows:

Forward Floor Skin	27
Turntable	152
Aft Floor Skin	24
Asymmetric Fairing	58
Thruster Assembly	29
VVSA	34

Thermocouples are connected to a Pace Engineering Company reference junction operating at $150^{\circ} \pm 0.2^{\circ}\text{F}$.

4.3 Nickel

The nickel used for the model shells was electroplated. The nickel used for the metric floor plate was sheet stock (half hard).

Both types of nickel are estimated by the manufacturers to contain less than 1% impurities. However, thermodynamic properties will be measured at room temperature as a check. Standard tables providing the variation of thermal properties with temperature will ultimately be used in data reduction.

5.0 DATA REQUIRED

Data collected will consist of tabulated data, plotted data, and photographic data (shadowgraphs and installation photographs). The requirements for each phase of testing will vary. See the appendix for definitions of symbols used subsequently.

5.1 Tabulated Data

5.1.1 Tunnel Freestream Parameters

Tunnel freestream parameters will be provided for all phases of testing:

$$T_{T\infty}, T_{\infty}, P_{T\infty}, P_{\infty}, \rho_{\infty}, \rho_{T\infty}, V_{\infty}, M_{\infty}, q_{\infty}, Re/in$$

5.1.2 Boundary Layer Survey, Phase I

During the boundary layer survey, the parameters under 5.1.1 will be listed along with δ .

5.1.3 Flat Plate Reference Runs, Phase II

During this phase of testing, parameters under 5.1.1 will be provided along with the following:

$$T \text{ vs } t \text{ (for a few selected thermocouples), } h_o, P_o,$$

$$R_{e_x} = 0$$

h_o and P_o will be provided for each thermocouple and orifice, respectively.

5.1.4 Protuberance Testing, Phase III

During this phase of testing, parameters under 5.1.1 will be provided along with the following:

$$h, h/h_o, CP, P/P_o, \beta$$

These parameters (except β) will be provided for each thermocouple and orifice, respectively.

5.2 Plotted Data

5.2.1 Boundary Layer Survey, Phase I

During this phase of testing the following shall be plotted

$$N = Z/\delta \text{ vs } \frac{M}{M_\infty}, \frac{P_{Tj}}{P_{T_\infty}}, \frac{u_j}{U_\infty}$$

for each boundary layer rake pressure tap.

5.2.2 Flat Plate Reference Runs, Phase II

During this phase of testing the following shall be plotted:

T vs t (for a few selected thermocouples).

In addition, h_o and P_o will be printed out on a plan schematic of the floor at each thermocouple and pressure tap, respectively.

5.2.3 Protuberance Testing, Phase III

During this phase of testing the following shall be plotted:

T vs t (for a few selected thermocouples)

X vs h/h_o

In addition, h/h_o and P/P_o will be printed out on a plan schematic,

The X plots will be on tunnel centerline only at zero yaw. These plots will not extend over the model.

5.3 Photographic Data

Installation photographs will be taken when requested by the test director. Shadowgraphs will be taken for each model configuration and Mach number. The field of view and the spark source locations are provided on figure 3.

REFERENCES

1. Test Control Dwg. 1T22216, Model, Protuberance - Development Test - TCD, dated 12 July 1967.
2. Douglas Report DAC-59809, The Douglas Aerophysics Laboratory Four-Foot Trisonic Wind Tunnel, dated October 1967.
3. Naismith, A., Measurement of Aerodynamic Heat Transfer in Intermittent Wind Tunnels, Royal Aircraft Establishment Technical Report CP-780, dated January 1964.
4. McMahan, H. M., "An Experimental Study of the Effect of Mass Injection at the Stagnation Point of a Blunt Body," GALCIT Hypersonic Research Project, Memorandum No. 42, dated 1 May 1950.
5. Douglas Report DAC-59801, Improved Turbulent Skin Friction Coefficient Predictions Utilizing the Spalding-Chi Method, dated November 1966.

Table 1 Preliminary Run Schedule (Sheet 1 of 4)

Configu- ration Rake at STA 23	Run No.	M _∞	P _{T∞} (psia)	T _{T∞} (°F)	Re/in 10 ⁻⁶	β (Deg)	Data Take		Remarks
							T	P	
	1	2.5	27	70	.50	---	yes	yes	Start Phase I
	2	3.0	35		.50				
	3	↓	40		.55				
	4	3.5	40		.44				
	5	↓	65		.71				
	6	4.0	95		.90				
	7	↓	↓	↓					Repeat of No. 6
	8	4.5	80	150					
	9	↓	110	↓					
	10	5.0	110	150					
Rake at STA 188	11	2.5	27	70	.50				
	12	4.0	95	↓	.90				
	13	5.0	110	150	.90				
M ₁	14	2.5	27	70	.50				Start Phase II
	15	↓	↓	↓	↓				Repeat No. 14
	16	3.0	35		.50				
	17	↓	40		.55				
	18	3.5	40		.44				
	19	↓	65		.71				
	20	↓	↓	↓	↓				Repeat No. 19
	21	4.0	95	↓	.90				
	22	4.5	80	150					
	23	4.5	110	↓					
	24	↓	↓	↓					Repeat No. 23
	25	5.0	110	150					
	26	↓	↓	↓	↓				Repeat No. 25

Table 1 Preliminary Run Schedule (Sheet 2 of 4)

Configu- ration M_1 M_2	Run No.	M_∞	P_{T_∞} (psia)	β (Deg)	Data Taken		*Light Source	Remarks	
					T	P			
	27	2.5	27	0	yes	yes	125	Asymmetric Model	
	28	3.0	35						
	29	3.5	40						
	30	4.0	95						
	31	4.5	110						
	32	5.0	110						
	33	5.0	↓			no		Pickup rest T.C. data	
	34	4.5	110						
	35	4.0	95						
	36	3.5	40						
	37	3.0	35						
	38	2.5	27						
M_1 M_3	39	2.5	27		Yes	Yes	155	Thrustor	
	40	3.0	45						
	41	3.5	65						
	42	↓	↓						Repeat No. 41
	43	↓	↓	+12					
	44	↓	↓	-12					
	45	4.0	95	0					
	46	↓	↓	+12					
	47	↓	↓	-12					
	48	4.5	80	0					
	49	↓	↓	+24					
	50	↓	↓	-24					
	51	↓	↓	↓					Repeat at No. 50
	52	5.0	110	0					

* Shadowgraph light source tunnel station.

Table 1 Preliminary Run Schedule (Sheet 3 of 4)

Configu- ration M_1 M_4	Run No.	M_∞	P_{T_∞} (psia)	β (Deg)	Data Taken		Light Source	Remarks			
					T	P					
	53	2.5	27	0	yes	yes	147.8	VVSA + Thrustor			
	54	3.0	40	+							
	55	3.5	65	+12							
	56			-12							
	57	↓	↓	↓				Repeat No. 56			
	58	4.0	110	~							
	59	↓	↓	+12							
	60	↓	↓	↓				Repeat No. 59			
	61	↓	↓	-12							
	62	4.5	80	0							
	63	↓	↓	+24							
	64	↓	↓	↓				Repeat No. 63			
	65	↓	↓	-24	↓	↓					
	69	↓	↓	↓	yes	no		Pickup rest of T.C. data.			
	70	2.5	27	0							
	71	3.0	40	0							
	72	3.5	65	0							
	73	↓	↓	+12							
	74	↓	↓	-12							
	75	4.0	110	0							
	76	↓	↓	+12							
	77	↓	↓	-12							
	78	4.5	80	0							
	79	↓	↓	+24							
	80	↓	↓	-24	↓	↓	↓				

Table 1 Preliminary Run Schedule (Sheet 4 of 4)

Configura- tion M_1 M_4	Run No.	M_∞	$P_{T\infty}$ (psia)	β (Deg)	Data Taken		Light Source	Remarks
					T	P		
	66	5.0	110	0	Yes	Yes	147.8	
	67			+24				
	68			-24				
	81			0		No		
	82			+24				
	83			-24				Last Run

TABLE 2

MODEL CONFIGURATION SYMBOLS

SYMBOL	DESCRIPTION
M_1	Metric Floor Plate
M_2	Asymmetric Model
M_3	Thrustor Assembly
M_4	VVSA - Thrustor Assembly Combination

Table 3 Instrumentation Locations for Turntable Skin (Sheet 1 of 3)

THERMOCOUPLES

T.C. No	X	Y	T.C. No	X	Y	T.C. No	X	Y
1	-11.000	+16.000	19	-5.000	+12.000	37	+3.000	+10.000
2	-1.000		20	-3.000		38	+5.000	
3	+1.000		21	-1.000		39	+9.000	
4	+3.000		22	+1.000		40	+11.000	
5	-12.500	+14.000	23	+3.000		41	+15.000	
6	-11.000		24	+5.000		42	-17.000	+8.000
7	-9.000		25	+7.000		43	-15.000	
8	-7.000		26	+9.000		44	-11.000	
9	-5.000		27	+11.000		45	-9.000	
10	-1.000		28	+13.000		46	-7.000	
11	+1.000		29	-17.000	+10.000	47	-3.000	
12	+9.000		30	-15.000		48	-1.000	
13	+11.000		31	-11.000		49	+1.000	
14	-15.000	+11.500	32	+7.000	+11.000	50	+3.000	
15	-13.000	+12.000	33	-5.000	+10.000	51	+5.000	
16	-11.000		34	+3.000		52	+7.000	
17	-9.000		35	+1.000		53	+9.000	
18	-7.000		36	+1.000		54	+13.000	

Refer to figure 4 for schematic

Table 3 Instrumentation Locations for Turntable Skin (Sheet 2 of 3)

THERMOCOUPLES

T.C. No	X	Y	T.C. No	X	Y	T.C. No	X	Y
55	-9.000	+6.000	89	-7.000	+2.000	123	-3.000	-10.000
56	-7.000		90	-5.000		124	-1.000	
57	-5.000		91	-3.000		125	+1.000	
58	-3.000		92	-1.000		126	-15.000	-11.500
59	-1.000		93	+1.000		127	-13.000	-11.000
60	+1.000		94	+11.000		128	-11.000	-12.000
61	+3.000		95	+13.000		129	-9.000	
62	+5.000		96	+15.000		130	-7.000	-11.000
63	+7.000		97	+19.000		131	-7.000	-12.000
64	+9.000		98	-1.000	+1.000	132	3.000	
65	+13.000		99	-13.000	0	133	-1.000	
66	+15.000		100	-11.000		134	+1.000	
67	-11.000	+4.000	101	-9.000		135	+3.000	
68	-9.000		102	-7.000		136	-12.500	-14.000
69	-7.000		103	-5.000		137	-11.000	
70	-5.000		104	-3.000		138	-9.000	
71	-3.000		105	-1.000		139	-7.000	
72	-1.000		106	+11.000		140	-3.000	
73	+1.000		107	+13.000		141	-1.000	
74	+3.000		108	+15.000		142	+1.000	
75	+5.000		109	+17.000		143	+5.000	
76	+7.000	+4.500	110	+19.000		144	-12.500	-15.500
77	+9.000	+4.000	111	-17.000	-8.000	145	-11.000	-16.000
78	+11.000		112	-15.000		146	-9.000	
79	+13.000	+4.500	113	-13.000		147	-7.000	-15.250
80	+17.000	+4.000	114	-11.000		148	-5.000	-16.000
81	-8.000	+3.000	115	-3.000		149	-1.000	
82	-4.000		116	-1.000		150	+1.000	
83	-2.000		117	-5.000		151	+3.000	
84	+1.000		118	+13.000		152	-5.000	
85	-13.000	+2.000	119	-17.000	-10.000			
86	-11.000		120	-15.000				
87	-9.000		121	-11.000				
88	-8.000	+1.500	122	-9.000				

Table 3 Instrumentation Locations for Turntable Skin (Sheet 3 of 3)

PRESSURE TAPS

P.T. No.	X	Y	P.T. No.	X	Y	P.T. No.	X	Y
1	-3.000	+14.000	28	-3.000	-4.000	55	-5.000	-8.000
2	+3.000		29	-1.000		56	+1.000	
3	-9.000	+10.000	30	+1.000		57	+3.000	
4	-13.000	+8.000	31	+3.000		58	+7.000	
5	-5.000		32	+5.000		59	+9.000	
6	-11.000		33	+7.000	-4.500	60	+11.000	
7	+17.000		34	+9.000	-4.000	61	+17.000	
8	-19.000	+6.000	35	+11.000		62	-5.000	-10.000
9	-1.000	-1.000	36	+13.000	-4.500	63	+3.000	
10	-13.000	-2.000	37	+17.000	-4.000	64	+5.000	
11	-11.000		38	-13.000	-6.000	65	+9.000	
12	-9.000		39	-11.000		66	+11.000	
13	-8.000	-1.500	40	-9.000		67	+15.000	
14	-7.000	-2.000	41	-7.000		68	-5.000	-12.000
15	-5.000		42	-5.000		69	+5.000	
16	-3.000		43	-3.000		70	+7.000	-11.000
17	-1.000		44	-1.000		71	+9.000	-12.000
18	0		45	+1.000	-5.750	72	+11.000	
19	+11.000		46	+3.000	-6.000	73	+13.000	
20	+13.000		47	+5.000		74	+3.000	-14.000
21	+15.000		48	+7.000		75	+7.000	
22	+19.000		49	+9.000		76	+9.000	
23	-13.000	-4.500	50	+11.000		77	-3.000	-16.000
24	-11.000	-4.000	51	+13.000		78		
25	-9.000		52	+15.000		79		
26	-7.000	-4.500	53	-9.000	-8.000	80		
27	-5.000	-4.000	54	-7.000		81		

TABLE 4
INSTRUMENTATION LOCATIONS FOR FORWARD FLOOR SKIN

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y
1	15.000	+18.000	15	21.750	+6.000
2	23.000	+14.000	16	35.000	+2.000
3	21.000		17	33.000	
4	19.000		18	31.000	
5	31.000	+ 8.000	19	29.000	
6	29.000		20	27.000	
7	27.000		21	37.000	0.000
8	25.000		22	35.000	
9	23.000		23	33.000	
10	21.250		24	31.500	
11	29.000	+ 6.000	25	33.000	-2.000
12	27.000		26	31.000	
13	25.000		27	29.000	
14	23.000				

PRESSURE TAPS

P. T. No.	X	Y	P. T. No.	X	Y
1	33.000	+6.000	4	27.000	-2.000
2	31.000		5	23.000	
3	35.000	-2.000	6	15.00	-18.000

Refer to figure 5 for schematic

TABLE 5
INSTRUMENTATION LOCATIONS FOR AFT FLOOR SKIN

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y
1	28.000	+14.000	13	44.000	+2.000
2	36.000		14	24.000	0.000
3	44.000		15	26.000	
4	21.000	+6.000	16	28.000	
5	28.000		17	30.000	
6	36.000		18	32.000	
7	44.000		19	34.000	
8	24.000	+2.000	20	36.000	
9	28.000		21	38.000	
10	32.000		22	40.000	
11	36.000		23	42.000	
12	40.000		24	44.000	

PRESSURE TAPS

P. T. No.	X	Y	P. T. No.	X	Y
1	24.000	-2.000	8	28.000	-6.000
2	28.000		9	36.000	
3	32.000		10	44.000	
4	36.000		11	28.000	-14.000
5	40.000		12	36.000	
6	44.000		13	44.000	
7	21.000	-6.000			

See figure 6 for schematic

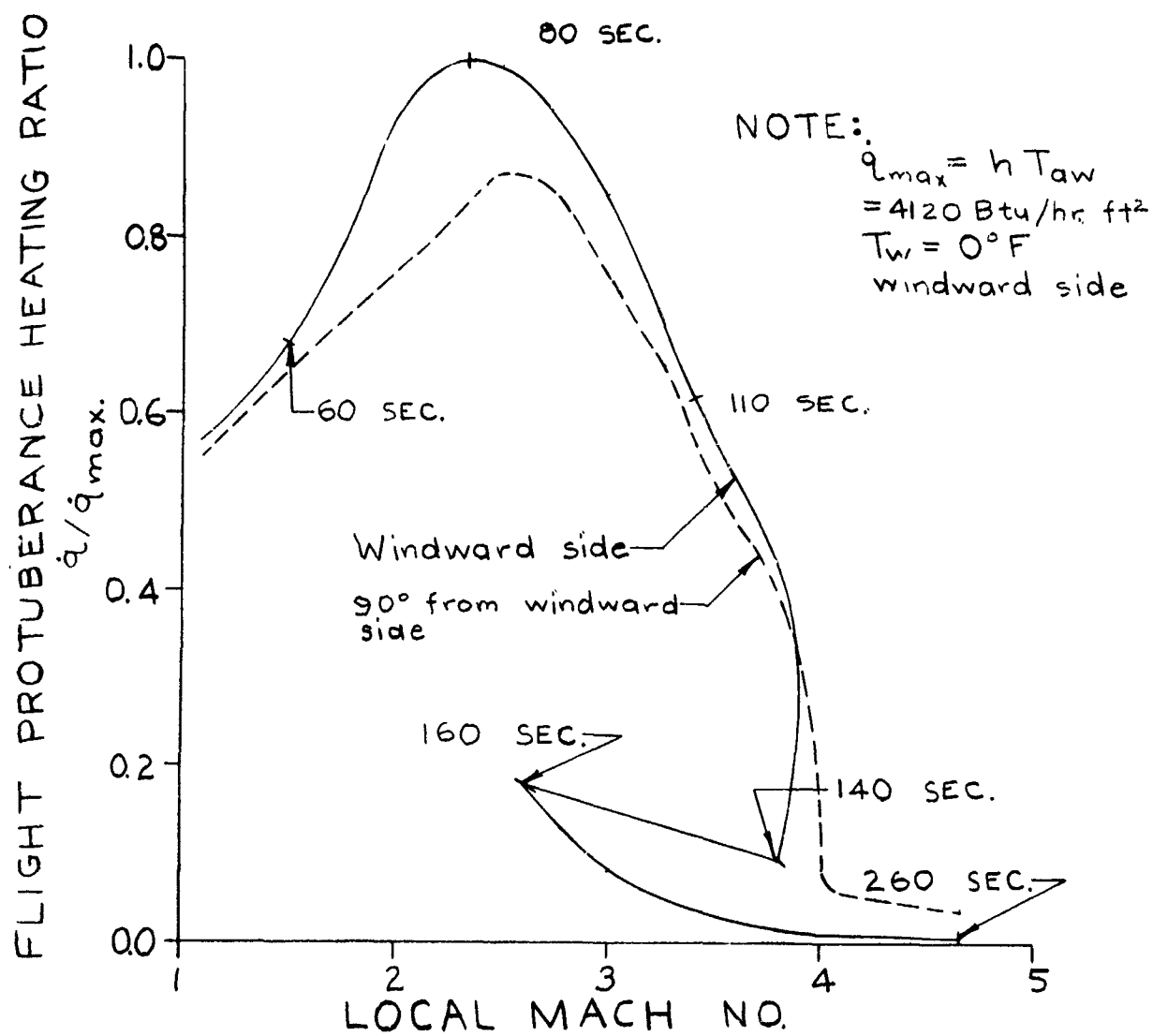


FIGURE 1. MOL Flight Protuberance Heating History

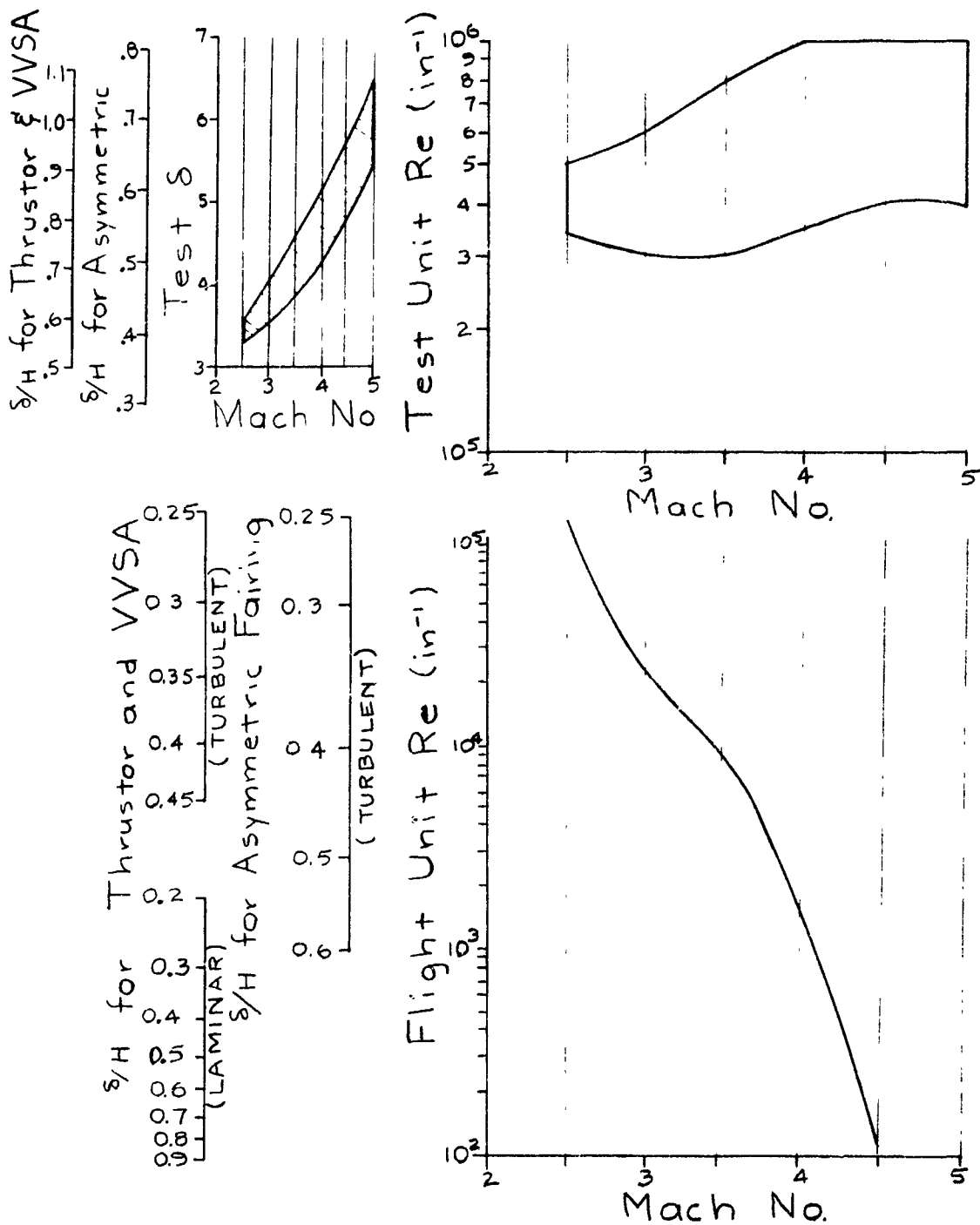


FIGURE 2. Comparison of Flight and Test Unit Reynold's Number and Boundary Layer Thickness

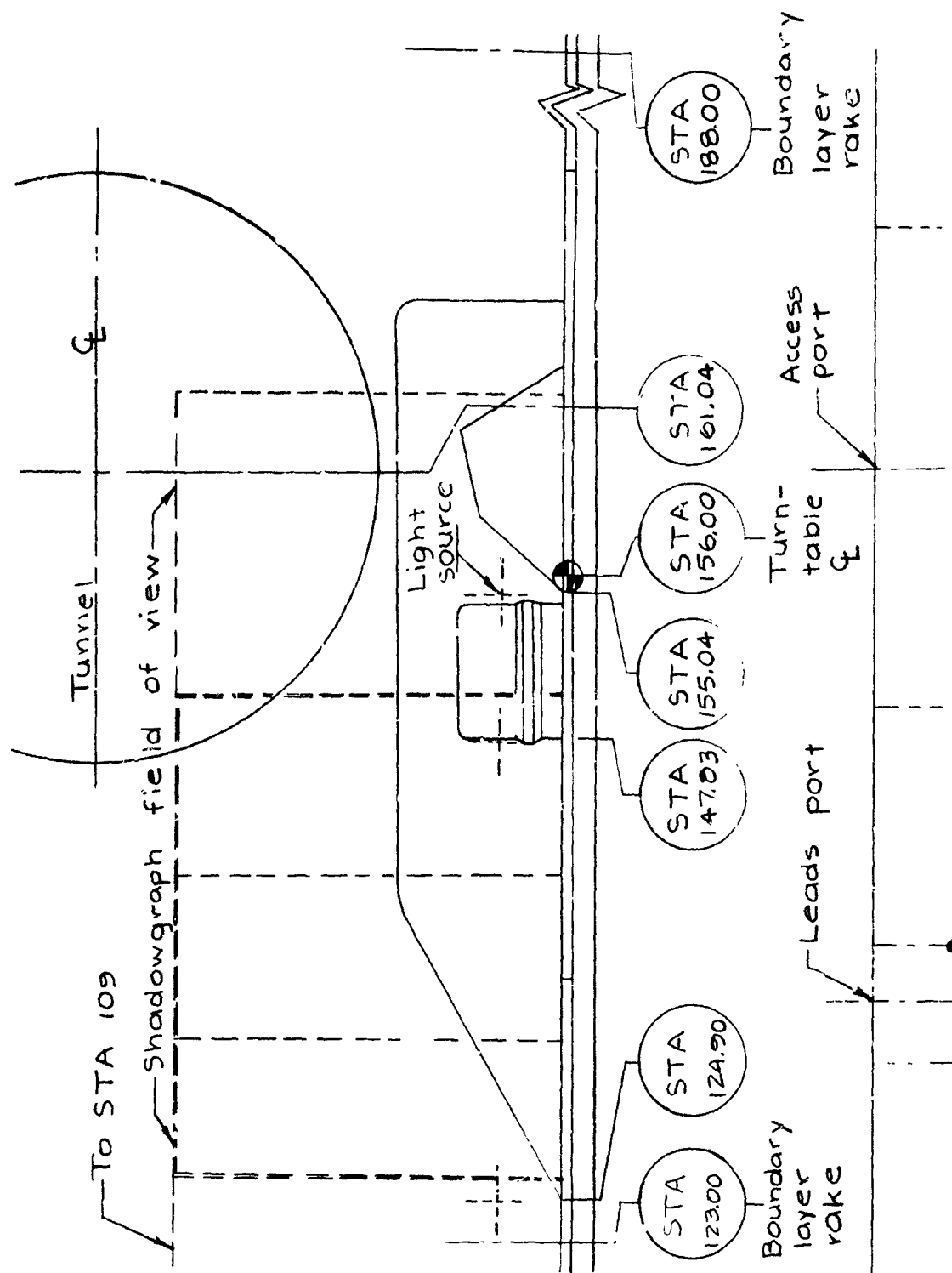
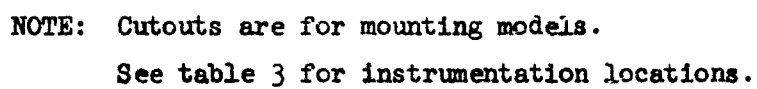
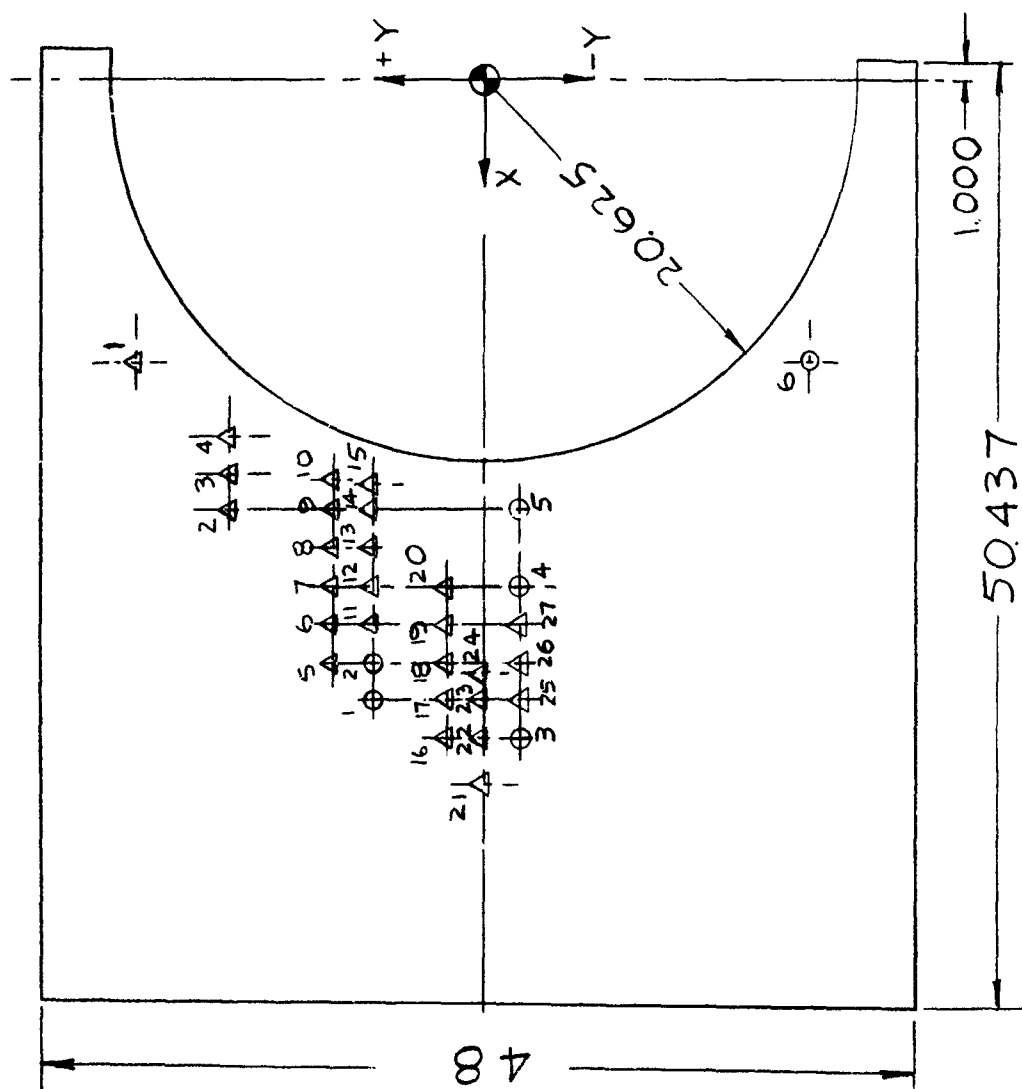


FIGURE 3. Schematic of Model Installations in Douglas Aerophysics Laboratory Four-Foot Trisonic Wind Tunnel

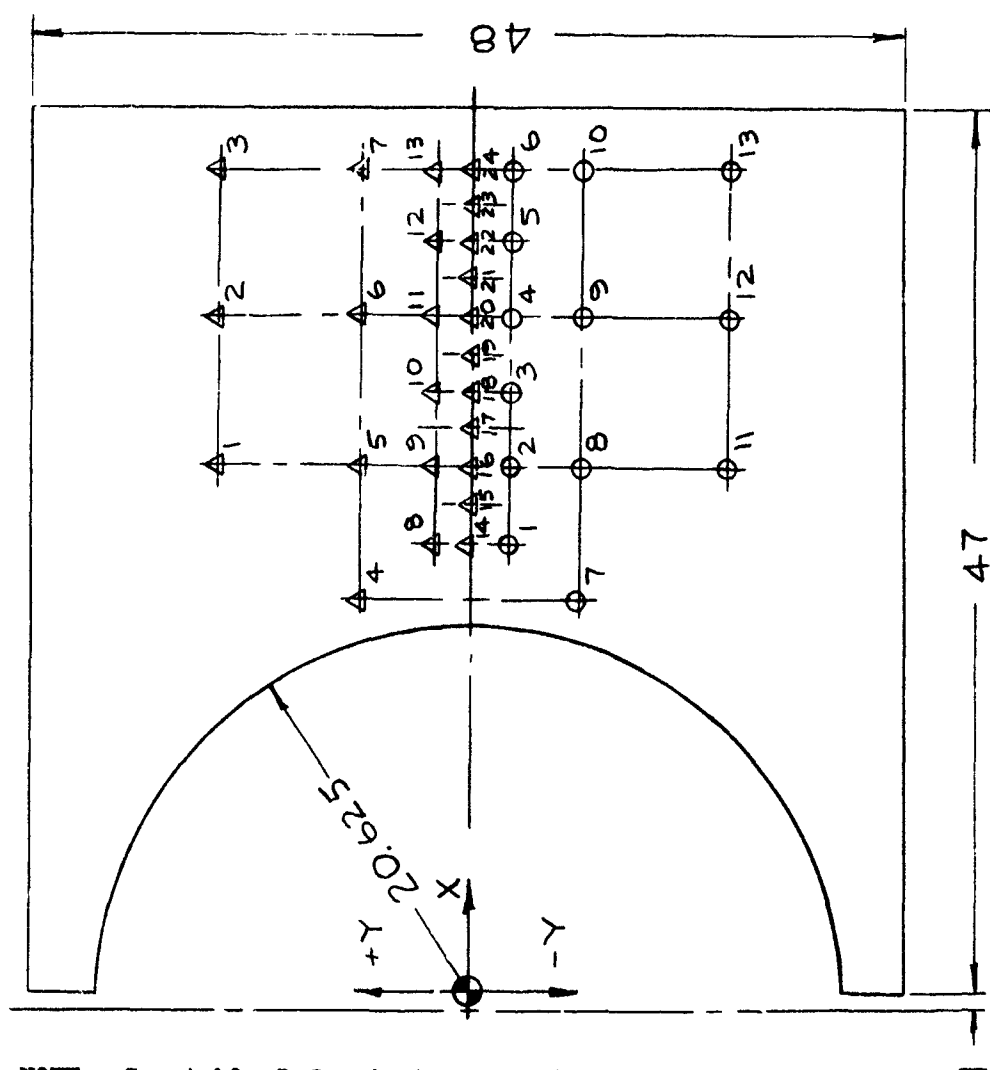


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NOTE: See table 4 for instrumentation locations

FIGURE 5. Forward Floor Skin



NOTE: See table 5 for instrumentation locations

FIGURE 6. Aft Floor Skin

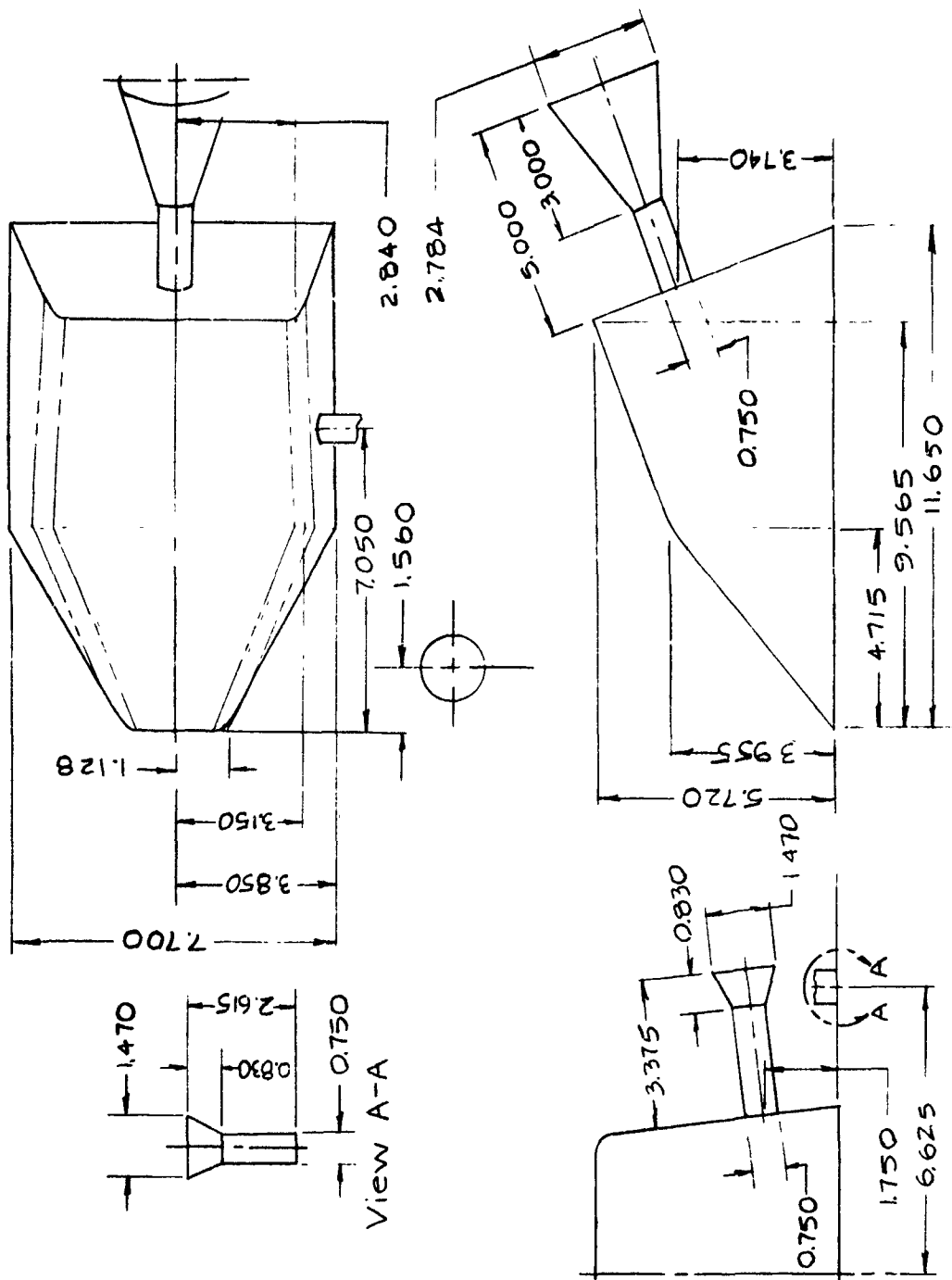


FIGURE 7. Thrustor Assembly Model Basic Dimensions

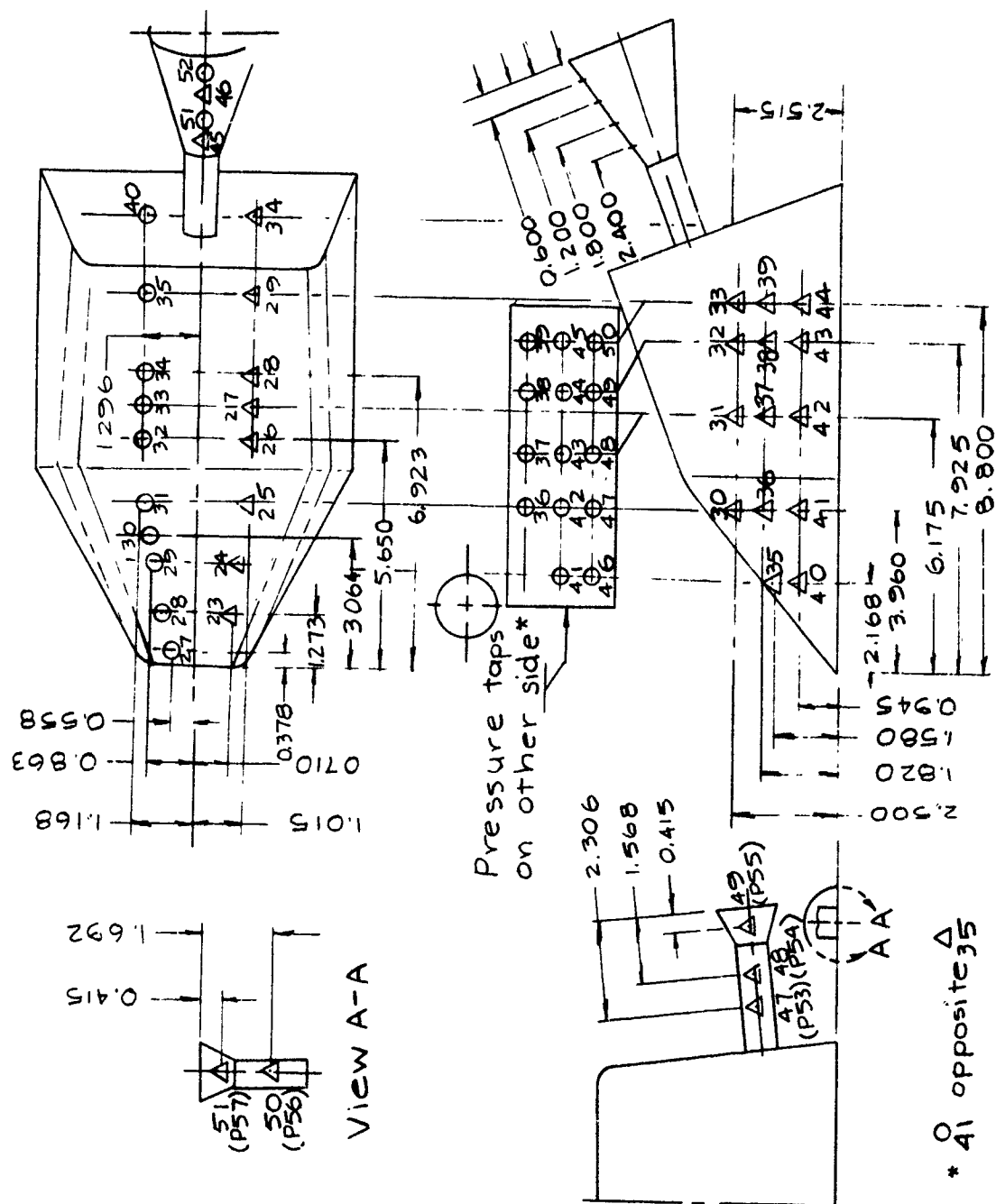


FIGURE 8. Thruster Assembly Model Instrumentation Locations

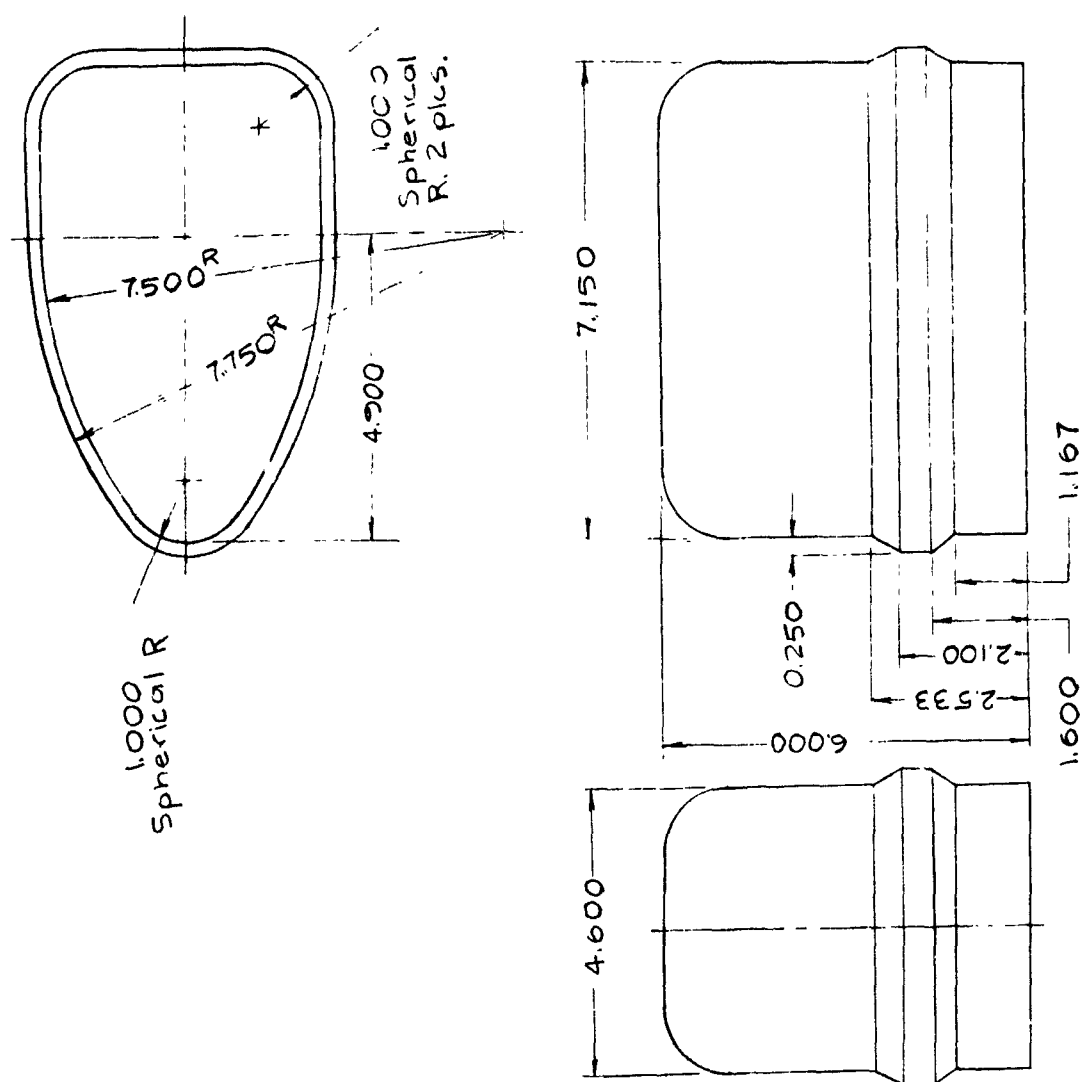


FIGURE 9. VVSA Model Basic Dimensions

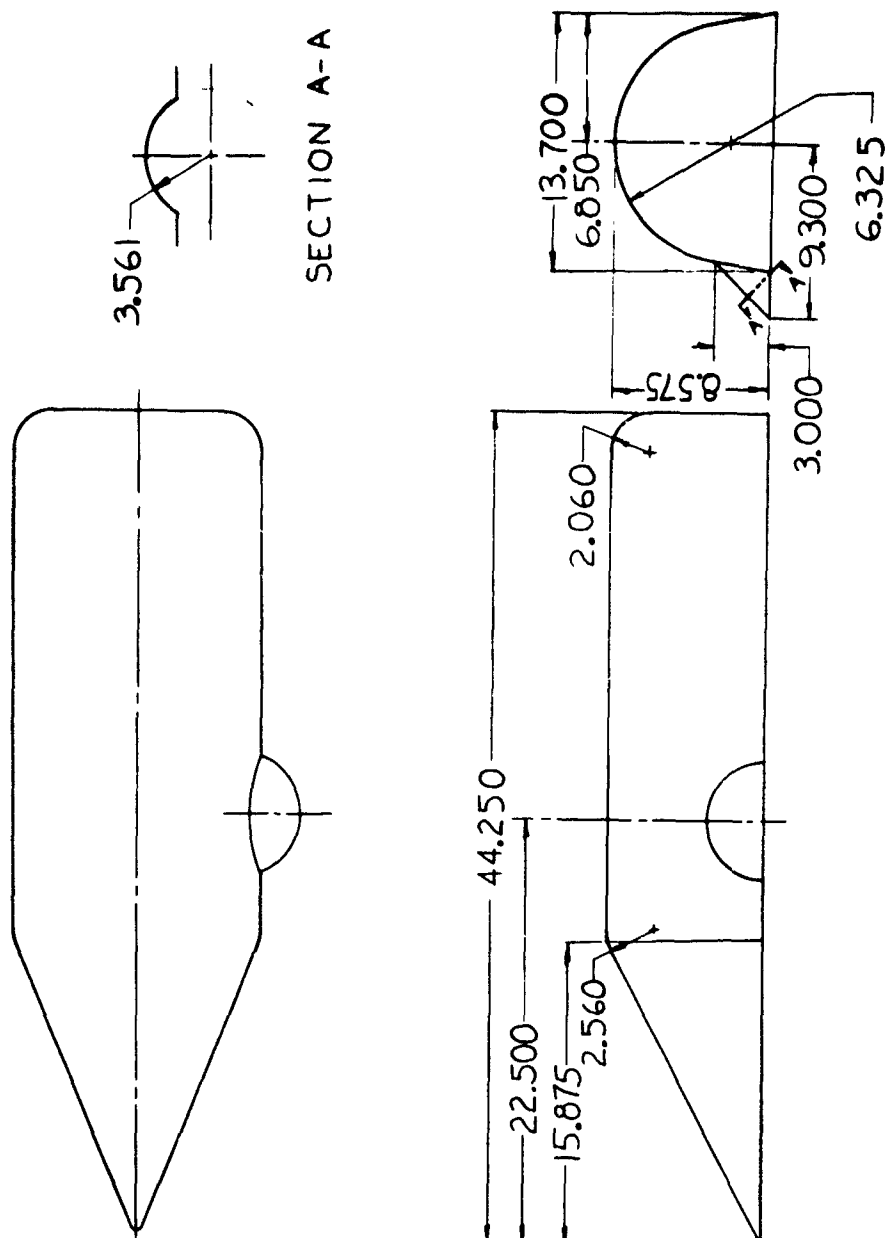


FIGURE 11. Asymmetric Model Basic Dimensions

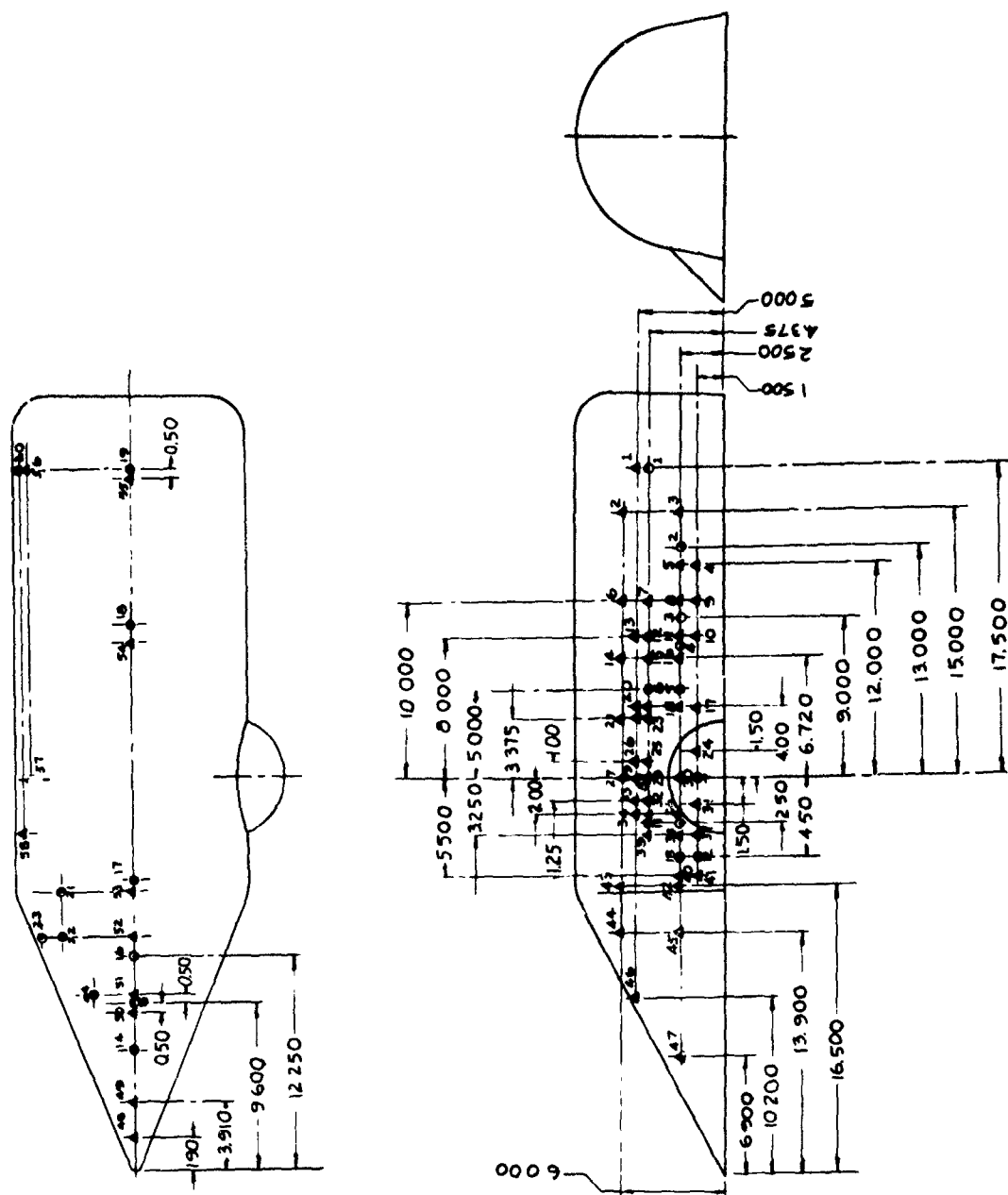


FIGURE 12. Asymmetric Model Instrumentation Locations

APPENDIX I

EQUATIONS AND DEFINITIONS OF SYMBOLS

EQUATIONS

Heat Transfer Calculations

If it is assumed that there are no losses to the environment such that all heat into the model is stored in the skin, the heat transfer rate can be expressed as

$$\dot{q} = F_q w d C_p \frac{dT}{dt}$$

From the definition of heat transfer coefficient, and using \dot{q} from the above equation,

$$h = \frac{\dot{q} F_h}{T_{aw} - T}$$

T is a temperature calculated at the midpoint of a quadratic determined from 21 consecutive thermocouple measurements.

Equations for some of the symbols used above:

$$F_q = \frac{\sin \beta}{\beta}$$

$$F_h = \frac{\tan \beta}{\beta}$$

$$\beta = \left(-1.5 + \sqrt{2.25 + 3 \lambda} \right)^{1/2}$$

$$\lambda = \frac{w d C_p}{T_{aw} - T_w} \frac{dT}{dt} \frac{d}{k}$$

$$T_{aw} = T \left(1 + 0.2 (0.89) M^2 \right)$$

APPENDIX I CONT'D

In addition to the above value of h , a theoretical value will be calculated from

$$h_o = 0.58 C_f \rho_\infty U_\infty C_{p_\infty}$$

C_f is a local turbulent skin friction coefficient that will be calculated by the Spalding-Chi method, reference 2

This will probably be used as a reference to compare with test data and to calculate h/h_o during the test (final data reductions would use the h_o data collected during the test).

The parameters F_h , F_q , etc. are used to account for temperature gradients through the skin thickness. Development of these is provided in reference 3.

Boundary Layer Survey Calculations

During the boundary layer survey, several freestream parameters will be calculated and printed out using P_{T_∞} , T_{T_∞} , and M_∞ and NACA 1135 equations. In addition, the adiabatic wall temperature T_{aw} will be calculated using the equation in the previous section.

For each of the probes in the boundary layer rake P_j' , M_j , T_j , T_{Tj} , U_j , $(\rho u)_j$, and $(\rho u^2)_j$ will be calculated. Equations to be used are as follows:

If the measured pressure at one probe is P_j' , M_j can be calculated from the following:

$$\frac{P_w}{P_j} = \left(1 + \frac{M_j^2}{5} \right)^{-7/2} \quad \text{if} \quad \frac{P_w}{P_j} \leq .5283$$

APPENDIX I CONT'D

$$\frac{P_j}{P_w} = \left(\frac{6M_j^2}{5} \right)^{7/2} \left(\frac{6}{7M_j^2 - 1} \right)^{5/2} \quad \text{if } \frac{P_w}{P_j} > .5283$$

The latter is the Rayleigh supersonic pitot formula for $\lambda = 1.4$.

The static temperature at each pressure probe is then

$$T_j = T_\infty \left\{ \frac{\left(\frac{T_{aw} - T_w}{T_\infty} \right) \frac{M_j}{M_\infty} + \sqrt{\left(\frac{T_{aw} - T_w}{T_\infty} \right)^2 \left(\frac{M_j}{M_\infty} \right)^2 + \frac{4 T_w}{T_\infty} \left[1 + \frac{T_{aw}}{T_\infty} - \left(\frac{M_j}{M_\infty} \right)^2 \right]}{2 \left[1 + \left(\frac{T_{aw}}{T_\infty} \right) - \left(\frac{M_j}{M_\infty} \right)^2 \right]} \right\}^2$$

From this point, T_{Tj} , ρ_j , and u_j can be determined from

$$u_j = M_j \sqrt{1.4 (1716) T_j}$$

$$T_{Tj} = T_j \left(1 + \frac{M_j^2}{5} \right)$$

$$\rho_j = \frac{P_w}{1716 T_j} \text{ slug/ft}^3 \text{ if } P_w \text{ in lb/ft}^2, T \text{ in } ^\circ R$$

Calculation of the Pressure Coefficient

During Phase III testing, the pressure coefficient for each orifice will be calculated according to

$$CP = \frac{P - P_\infty}{q_\infty}$$

where P is the orifice pressure.

SYMBOLS AND DEFINITIONS

English Alphabet Symbols

<u>Symbol</u>	<u>Description</u>	<u>Common Units</u>
B_i	Biot modulus	dimensionless
C_p	Specific heat	Btu/lb-°F
C_{p_∞}	Freestream specific heat of air	Btu/lb-°F
CP	Pressure coefficient	dimensionless
C_f	Local turbulent skin friction coefficient	dimensionless
d	Nickel skin thickness	ft
F_o	Fourier modulus	dimensionless
F_q, F_h	Correction terms for conduction effects through the skin	dimensionless
h	Heat transfer coefficient	Btu/sec ft ² °F
H	Protuberance height	in
k	Thermal conductivity	Btu/sec ft °F
M	Mach number	dimensionless

SYMBOLS AND DEFINITIONS CONT'D

English Alphabet Symbols

<u>Symbol</u>	<u>Description</u>	<u>Common Units</u>
w	Density	slug/ft ³
X	Along tunnel Q_L tunnel station	inches
Y	Transverse to tunnel	inches
Z	Height above floor	inches, ft

Greek Symbols

α	Thermal diffusivity	ft ² /sec
β	Yaw, positive to right looking upstream	degrees
δ	Boundary layer thickness	inches, ft.
λ, β	Correction terms for conduction effects through nickel shell	dimensionless
ρ	Density of air	slug/ft ³

Subscripts

j	Pertaining to local static condition (except for P_j and P'_j) at a particular pressure tap on the boundary layer rake, $j = 1, 2, 3 \dots$ etc.
---	--

SYMBOLS AND DEFINITIONS CONT'D

English Alphabet Symbols

<u>Symbol</u>	<u>Description</u>	<u>Common Units</u>
N	Z/ δ ; nondimensionalized height above tunnel floor	dimensionless
P	Pressure	psia
P_j	A local stagnation pressure	psia
P'_j	A local stagnation pressure behind a normal shock	psia
q	Dynamic pressure	psia
q	Heat transfer rate	Btu/sec ft ²
Re/in	Unit Reynolds number	in ⁻¹
Re _{x=0}	Total Reynolds number at metric plate leading edge, or tunnel station 106.563	dimensionless
T	Temperature	°F, °R
T _{aw}	Adiabatic wall temperature	°F, °R
t	Time	seconds
U	Freestream air velocity	ft/sec
u	Local air velocity	ft/sec

SYMBOLS AND DEFINITIONS CONT'D

English Alphabet Symbols Cont'd

<u>Subscripts</u>	<u>Description</u>
o	Pertaining to flat plate reference data
T	Stagnation condition
T_{∞}	Freestream stagnation condition
W	Used for floor or wall static pressure or temperature
∞	Freestream condition or freestream static condition

APPENDIX II

STRENGTH ANALYSIS

INTRODUCTION

A detailed, formal strength report is not required by the Douglas Aerophysics Laboratory because facility personnel have been intimately involved with design and development of the models. An internal memorandum (A2-260-ABC1-11 dated 2-14-68) published by the Structural Analysis Branch has satisfied laboratory requirements, so only a brief summary of the results will be presented.

MOL Model M208 Strength Limitations

General

In the ensuing discussions, the terms "load factor" and "margin of safety" will have the following meanings:

The margin of safety is defined as

$$M. S. = \frac{f_a}{fL} - 1$$

Where M. S. is the margin of safety, f_a is the material ultimate or yield strength, f is the actual stress, and L is the load factor.

The load factor is used as a multiplier of the actual stress as shown in the equation. Test facilities ordinarily require that a load factor of 5 be used in conjunction with the material ultimate strength during routine model design.

APPENDIX II (CONT'D)

Comments concerning the strength of the important model components follow.

Forward and Aft Metric Floor Sections

The strength of each nickel floor skin is considered when assembled with the respective insulator panel. For a load of 3 psi tending to lift up the floor, both the nickel and insulator show a large, positive margin of safety for a load factor of 5.

Protuberance Models

Since the models are of very similar construction (i.e., the maximum unsupported area of nickel is a 3 inch square), the thruster only will be discussed, because it experiences the worst loads.

All panels of the module have a margin of safety of at least +0.47 (ultimate) for a load factor of 5. Mounting bolts for the module show a large, positive margin.

The mounting bolts are the weakest members in the nozzles. The bolts show a margin of safety of at least +0.30 (ultimate) based on a load factor of 5.

Turntable

The turntable mount and the turntable tie-down bolts, the turntable base and its tie down bolts all will withstand 3 psi tending to lift the floor. The smallest margin is +0.22 (ultimate) for a load factor of 5.

The turntable skin is the weakest structural member of all model parts. The skin is point supported on a bolt spacing of 10.00 inches in a square pattern. For a 2.5 psi differential pressure on the skin that causes it to bear on the point supports, a margin of +0.23 (ultimate) with a load factor of 3 can be shown.

APPENDIX II (CONT'D)

When a pressure of 3 psi tending to lift the floor is applied to the turntable skin, a margin of safety of +0.08 (ultimate) with a load factor of 1 can be shown. This margin will improve when the skin is precooled to -100°F , where the ultimate strength increases by 20%. When the protuberances are mounted, they will contribute to the strength.

CONCLUSIONS

The strength of the turntable skin is marginal. Preliminary tests run at the Douglas Aerophysics Laboratory indicate the adverse pressure differential of 3 psi will occur during tunnel start, shoe retraction, and tunnel shutdown, and the duration will be one-half second.

Ordinarily, the Douglas Aerophysics Laboratory requires that models exhibit a positive margin of safety for a load factor of five on the material ultimate strength, or a load factor of three on the yield strength, whichever is smaller. However, acceptance of the MOL model is consistent with established laboratory policy. Section 5.6 of reference 2, which is concerned with model design criteria, states, "The recommended allowable stresses for testing without Schlieren viewing and with glass replaced by steel blanks may be appreciably higher and in many cases unrestricted." The tunnel will, in fact, be run in the above configuration so the model meets facility requirements.